

Pentaquark Searches at CDF

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On behalf of

CDF Collaboration,

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1 – Outline

- ✓1 Short Intro.
- ✓2 Experimental Status.
- ✓3 CDF Data Samples.
- ✓4 Search for Exotic S=-2 Baryons.
- ✓5 Conclusion.

2 – Pentaquark Baryons

- The SU(3)-flavour multiplet \Rightarrow
- R.I.Jaffe & F.Wilczek,
hep-ph/0307341 \Rightarrow
- $S = -2$ exotic baryons:
 $\Rightarrow \Xi_{3/2}^{--}, \Xi_{3/2}^-$
 $\Rightarrow \Xi_{3/2}^0, \Xi_{3/2}^+$
 \Rightarrow Pentaquark “cascades”.
- The quantum numbers can be described only by five quarks.
- Bound states: $qqqq\bar{Q}$ or $[qq]^2\bar{Q}$ (e.g.: Jaffe&Wilczek, Karliner&Lipkin).
- Chiral soliton models (e.g.: D.Diakonov, V.Petrov, M.Polyakov, hep-ph/9703373).

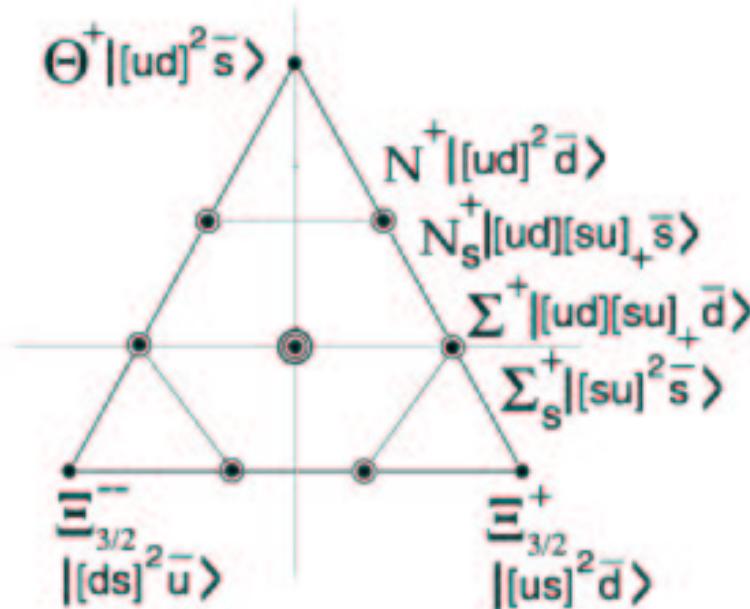


FIG. 1: Quark content of representative members of the $(q^4 \bar{q}) \overline{\textbf{10}}_f + \overline{\textbf{8}}_f$.

3 – Experimental Status

⇒ $\Theta^+(Z^+)$, predicted by Diakonov,Petrov,Polyakov, hep-ph/9703373:

- $\Theta^+, udud\bar{s}, M \sim 1.53 \text{ GeV}/c^2, \Gamma \sim 15 \text{ MeV}/c^2$
- [Wealth of experimental measurements:](#)

Group	Reaction and Mode	Mass, MeV/c ²	Num of St.Dev.
LEPS	$\gamma n \rightarrow K^- \Theta^+, \Theta^+ \rightarrow K^+ n$	1540	4.6
DIANA	$K^+ X e \rightarrow N \Theta^+, \Theta^+ \rightarrow K_s^0 p$	1539	4.4
CLAS	$\gamma d \rightarrow p K^- \Theta^+, \Theta^+ \rightarrow K^+ n$	1542	5.2 ± 0.6
SAPHIR	$\gamma p \rightarrow K_s^0 \Theta^+, \Theta^+ \rightarrow K^+ n$	1540	4.8
CLAS	$\gamma p \rightarrow p K^- \Theta^+, \Theta^+ \rightarrow K^+ n$	1555	7.8 ± 1.0
HERMES	$\gamma^* D \rightarrow K^- \Theta^+, \Theta^+ \rightarrow K_s^0 p$	1528	4.2...6.3
ZEUS	$e p \rightarrow \Theta^+ X, \Theta^+ \rightarrow K_s^0 p$	1521.5	3.9...4.6

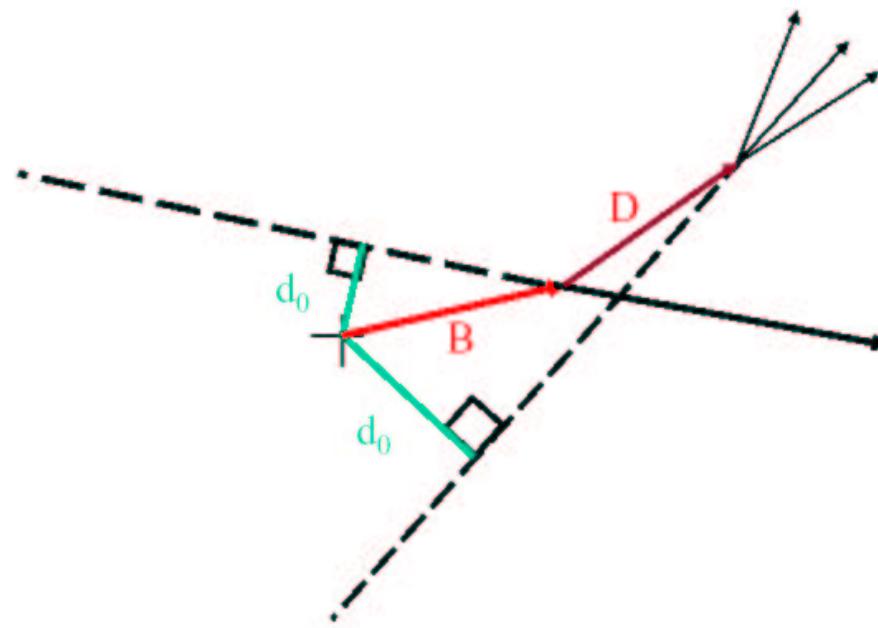
- ⇒ $\Xi_{3/2}$, $qsqs\bar{q}$, Jaffe & Wilczek predict $M \sim 1.750 \text{ GeV}/c^2$, $\Gamma \sim 22 \text{ MeV}/c^2$
- NA49 at SPS CERN, proton beam 158 GeV/c on a liquid H_2 fixed target, $\sqrt{s} = 17.2 \text{ GeV}$, $M = 1.862 \pm 0.002 \text{ GeV}/c^2$, Γ below a detector resolution. This talk presents a study on $\Xi_{3/2}$ production in CDF 2 Detector at $p\bar{p}$ collisions with $\sqrt{s}=1960 \text{ GeV}$.
- ⇒ Recently the evidence of charmed pentaquark state has been announced:
- H1, HERA e^+p collisions, excess in mass difference spectra $M(D^{*+}\bar{p}) - M(D^{*+})$ at $M(D^{*+}\bar{p}) = 3099 \pm 3 \pm 5 \text{ MeV}/c^2$ with Γ below an experimental resolution.
- ⇒ “Although the discoveries are striking, I don’t think they are so peculiar as to require introducing new interactions or modifying QCD as the basic theory of the strong interactions”, F.Wilczek, talk at Eur. Phys. Society, Aachen, Aug 03, hep-ph/0401034.

4 – Cascade Pentaquark Search at CDF.

- We have conducted a search for a cascade pentaquark $\Xi_{3/2} \rightarrow \Xi\pi$.
- Based on two data samples: Two Track Trigger and inclusive Jet with $E_T > 20 GeV$ threshold.
- Decay modes:
 - ✓ $\Xi_{3/2}^0 \rightarrow \Xi^-\pi^+$ +charge conjugation.
 - ✓ $\Xi_{3/2}^{--} \rightarrow \Xi^-\pi^-$ +charge conjugation.
- A well established $J^P = 3/2^+$ resonance $\Xi(1530)^0 \rightarrow \Xi^-\pi^+$ can serve as a calibrating signal.
 - ✓ $M_{PDG}(\Xi(1530)^0) = 1531.80 \pm 0.32 MeV/c^2$.
 - ✓ $\Gamma_{PDG}(\Xi(1530)^0) = 9.1 \pm 0.5 MeV/c^2$.
- A novel technique of a cascade hyperon Ξ^- tracking in a CDF Si vertex detector has recently been developed improving momentum and vertex resolution and significantly reducing a combinatorial background.

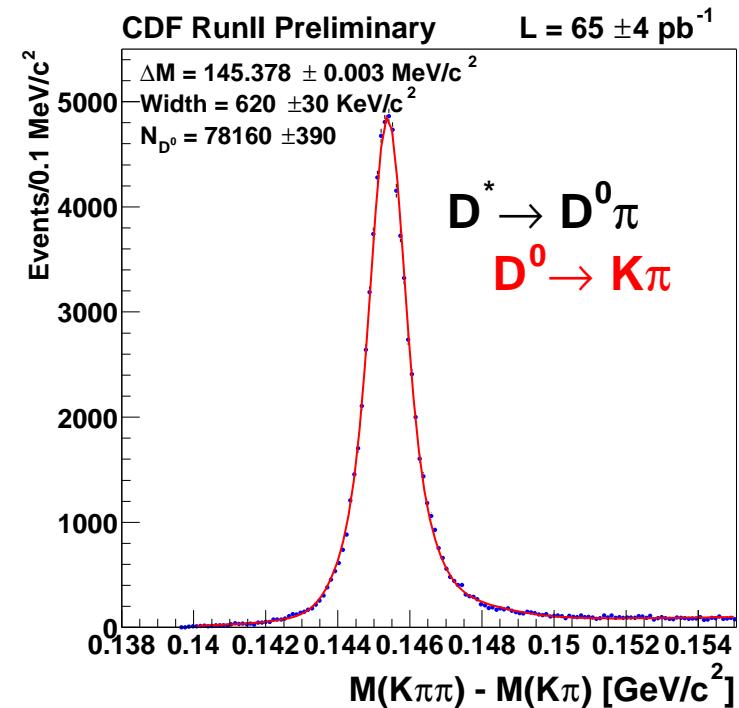
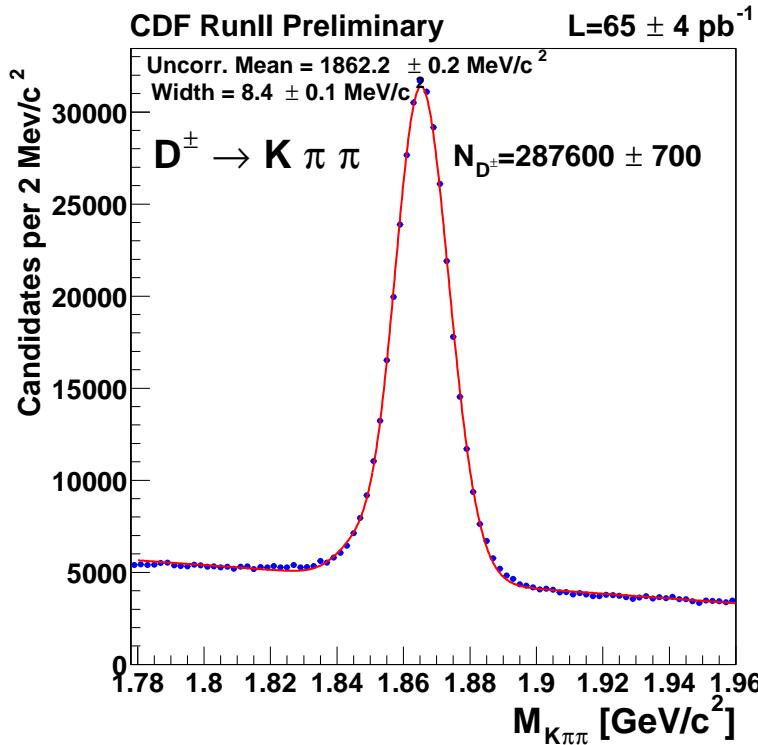
5 – CDF Data Sample and Triggers.

- Two Track Trigger: fast I.P. measurement with Si detector SVX.
 - ⇒ efficient for hadron modes
 - ⇒ 2 tracks of opposite charge
 - ⇒ $d_0^{1,2} > 100\mu m$,
 $p_T^{1,2} > 1.5 GeV/c$
 - ⇒ the momenta sum
 $p_T^1 + p_T^2 > 5.5 GeV/c$
- I.P. resolution
 $\sigma(d_0) = beam \oplus SiResol = 48\mu m$



CDF SVT: displaced track trigger requirement.

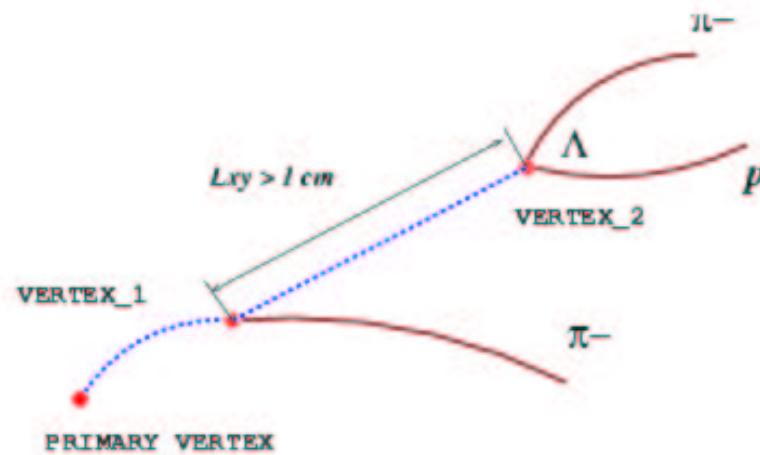
- The trigger allowed to collect large samples of D^0, D^+, D^{*+} .
- $\sim 0.5M D^{*+}$ with present $\mathcal{L} \sim 200 pb^{-1}$.



- Two Track Trigger: Rich physics in Charm and Beauty sector.
- Use complementary triggers: QCD Inclusive Jet $E_T > Thr$, Thr=20...GeV.
- Competitive data samples for studies of an exotic spectroscopy.

6 – Cascades in CDF 2 Detector.

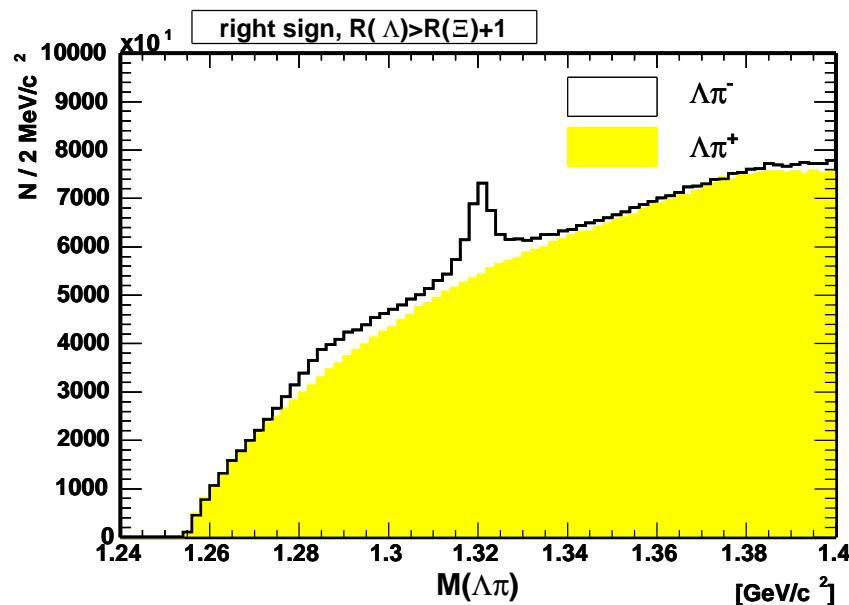
- Cascades $\Xi^- \rightarrow \Lambda^0 \pi^-$
reconstruction.
 - ⇒ Fit of vertex formed by
 $\Lambda^0 \rightarrow p\pi^-$.
 - ⇒ Fit three tracks to
common vertex: Λ^0 and
 π^- (“kink”).
 - ⇒ Seed the hits left by Ξ^-
back into Si Detector as
 $c\tau(\Xi^-) = 4.91\text{cm}$ for
tracking in Si Detector.
 - ⇒ Substantial background
reduction using SVX hits.
 - ⇒ Improved momentum
and vertex resolutions.



Cascade reconstruction and cuts.

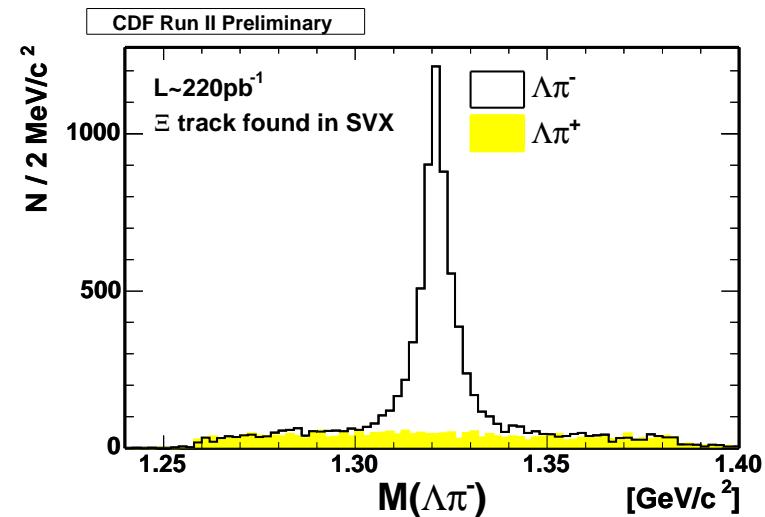
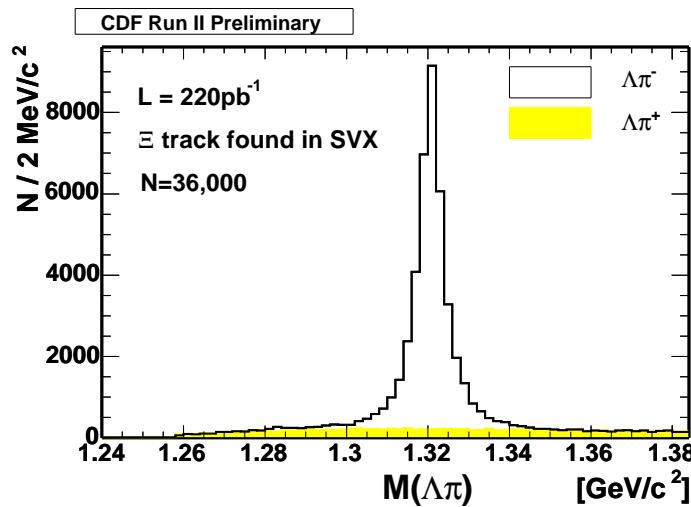
- Cascades $\Xi^- \rightarrow \Lambda^0 \pi^-$ reconstructed **without hits** in Si Detector involved, only with CDF outer tracker, COT.
- The clear signal, sitting on top of a large combinatorial background.

CDF Run II Preliminary.



Cascades, reconstructed with COT tracking only.
A fraction of TTT sample was used for this picture.

- Invariant mass $M(\Xi^- \rightarrow \Lambda^0\pi^-)$, wr. chrg. $M(\Lambda^0\pi^+)$ spectra.
- Ξ^- hyperon has track reconstructed in CDF Si detector (SVX).



Two displaced Tracks Trigger sample.

$$N(\Xi^-) = 19150 \pm 244$$

$$N(\bar{\Xi}^+) = 16736 \pm 218$$

$\times 18$ larger than NA49 sample.

Inclusive Jet Trigger: $E_T > 20\text{ GeV}$.

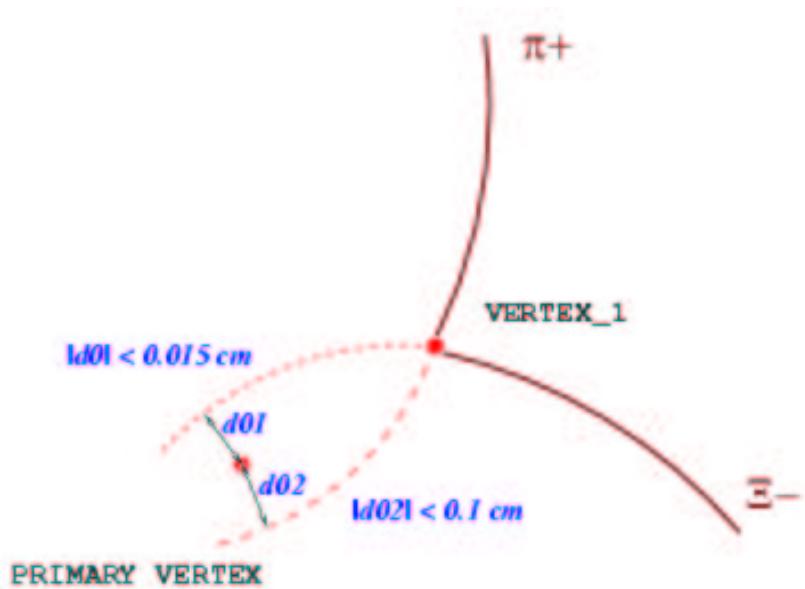
Complementary data set, soft jet thresh.

$$N(\Xi^-, \bar{\Xi}^+) = 4870 \pm 122$$

$\times 2$ larger than NA49 statistics.

7 – Analysis of $\Xi\pi$ Spectra.

- Having Ξ^- , $\bar{\Xi}^+$ hyperon tracks reconstructed in Si detector couple them with $\pi^{+,-}$ track.
- $M(\Xi) = M_{PDG} \pm 10 MeV/c^2$
- 2d-vertex Fit of $\Xi\pi$ track pair
- suppress comb.bgr. with pointing requirement $d0(\Xi) < 150 \mu m$ thanks to Si tracking.

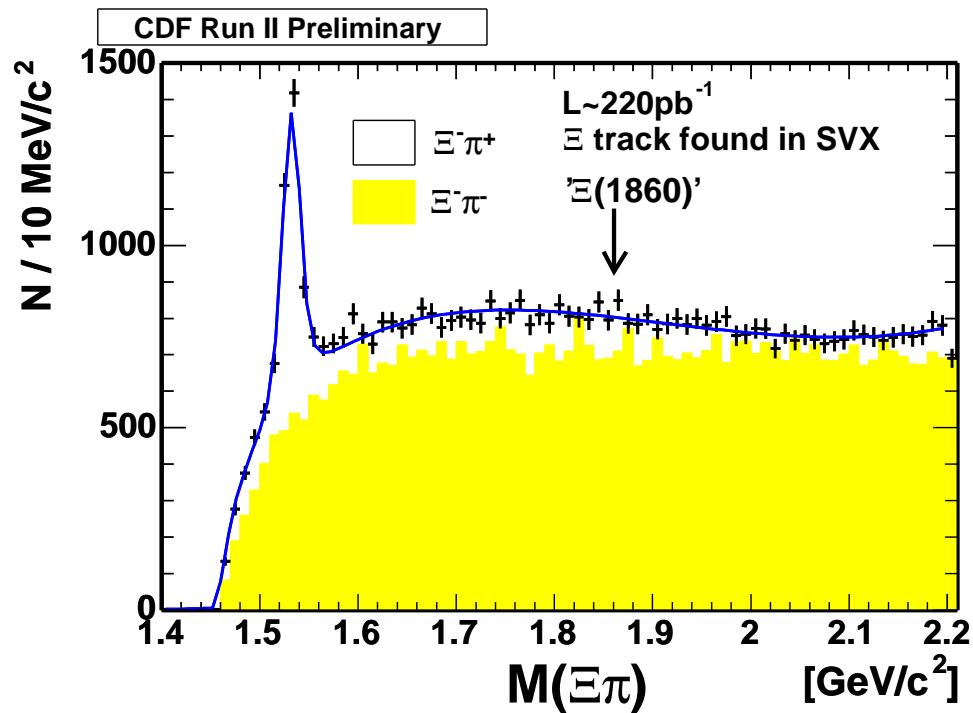


$\Xi\pi$ selection.

\Rightarrow Two Track Trigger data set, $\mathcal{L}=220\text{pb}^{-1}$

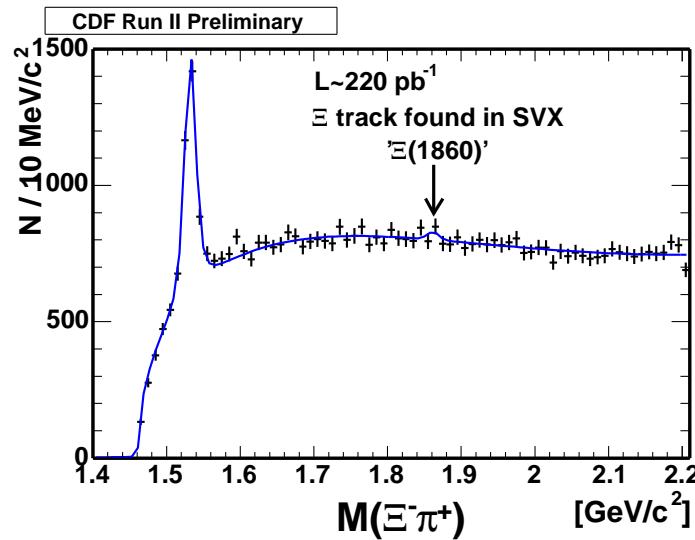
- Invariant mass spectra $M(\Xi^-\pi^{+-})$.
- The prominent peak of $\Xi(1530)^0 \rightarrow \Xi^-\pi^+$ is used as a reference signal.

- Fit $\Xi(1530)^0$ with
B.W. \otimes Gaussian:
- $\Gamma_{PDG}=9.1\text{ MeV/c}^2$
- $\sigma_{res}=5.8\pm0.5\text{ MeV/c}^2$
- Mass= $1532\pm4\text{ MeV/c}^2$
- Yield= 2182 ± 92 evts

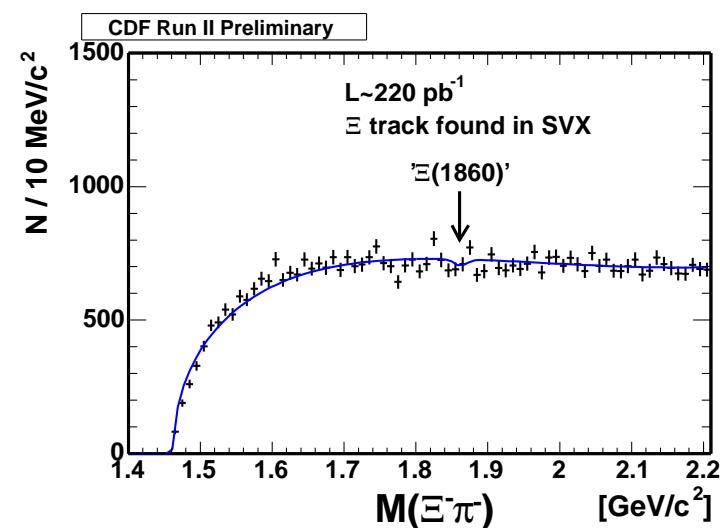


\Rightarrow Two Track Trigger data set, $\mathcal{L}=220\text{pb}^{-1}$

- Present two modes corresponding to two alleged Pentaquark states $\Xi_{3/2}^0$, $\Xi_{3/2}^{--}$ separately.
- Fit the mass region around $M=1862 \text{ Mev}/c^2$ claimed by NA49 with a Gaussian of $\sigma=8 \text{ MeV}/c^2$ and a 3rd order polynomial.



$N(\Xi_{3/2}^0) = 57 \pm 51$ events



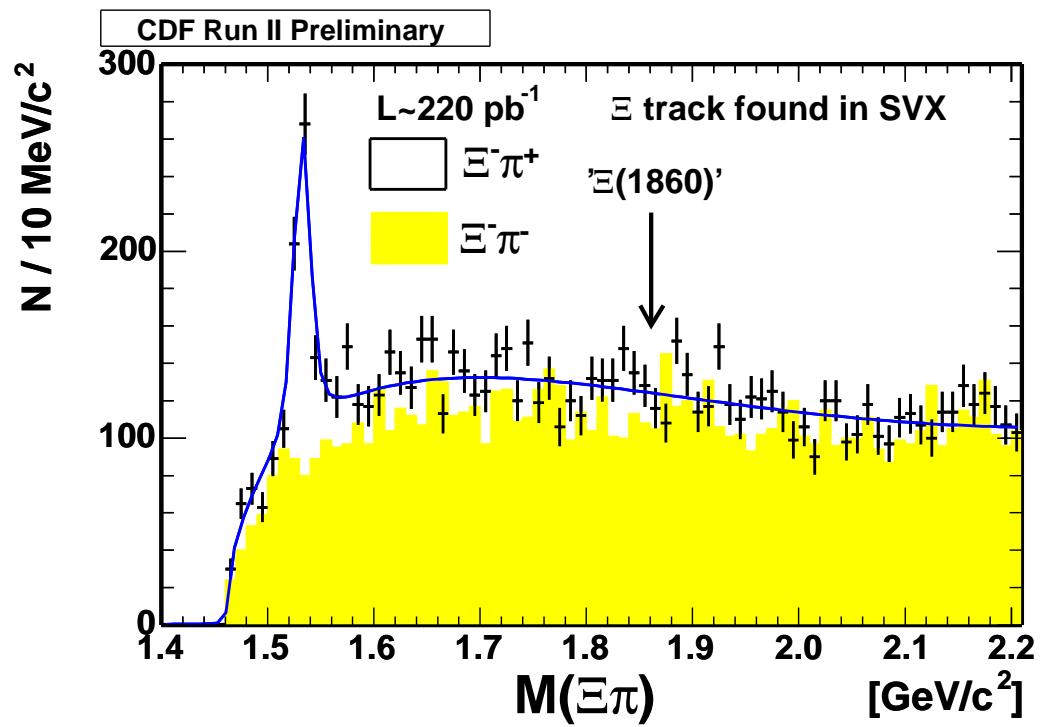
$N(\Xi_{3/2}^{--}) = -54 \pm 47$ events

- **No evidence of a pentaquark signal is seen in either mass spectrum.**

\Rightarrow Jet $E_T > 20 GeV$ sample, $\mathcal{L}=220 pb^{-1}$

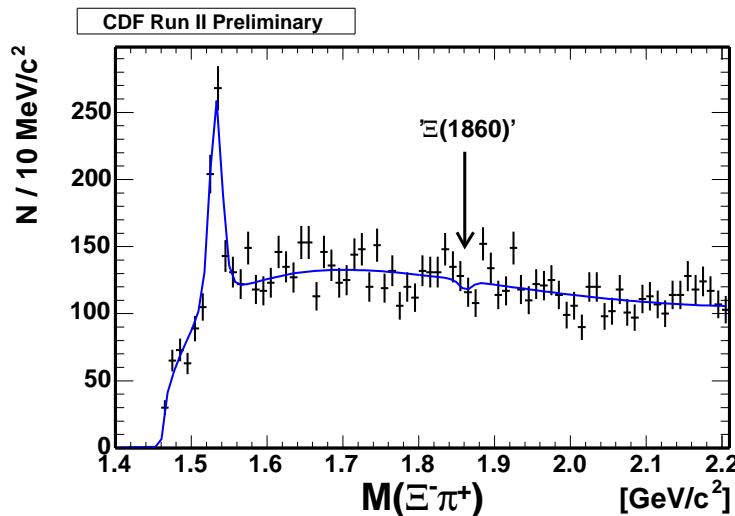
- The “Two Track Trigger” requirements bias the data set towards an enhanced content of charm- and beauty hadron modes. The bias may not be favourable to pentaquark production.
- We have performed a search in an independent data stream triggered by an inclusive jet trigger with a relatively soft threshold $E_T > 20 GeV$.

- Fit $\Xi(1530)^0$ with B.W. \otimes Gaussian:
- $\Gamma_{PDG} = 9.1 \text{ MeV}/c^2$
- $\sigma_{res} = 5.8 \text{ MeV}/c^2$
- Mass= $1532.3 \pm 0.8 \text{ MeV}/c^2$
- Yield= $387 \pm 34 \text{ evts}$

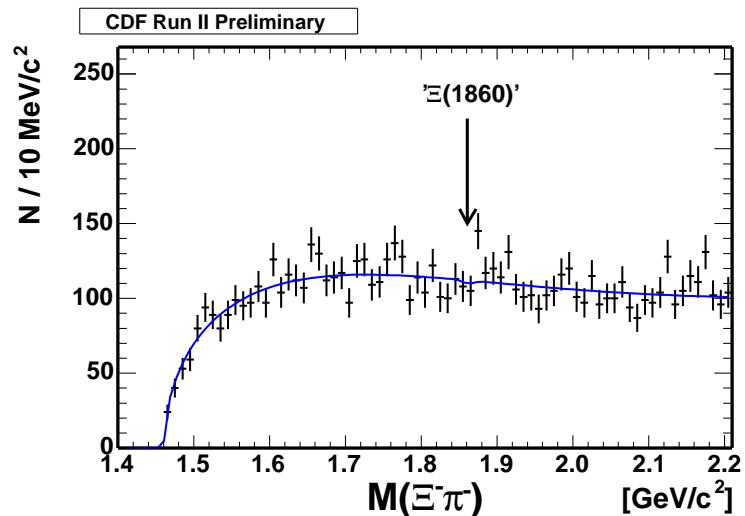


\Rightarrow Jet $E_T > 20\text{GeV}$ sample, $\mathcal{L}=220\text{pb}^{-1}$

- Again Fit the mass region around $M=1862 \text{ Mev}/c^2$ claimed by NA49 with a Gaussian of $\sigma=8 \text{ MeV}/c^2$ and a 3^{rd} order polynomial.



$$N(\Xi_{3/2}^0) = -14 \pm 19 \text{ events}$$



$$N(\Xi_{3/2}^{--}) = -4 \pm 18 \text{ events}$$

- No evidence of a pentaquark signal is seen here as well.
- \uparrow Set Upper Limits... \uparrow

8 – Results.

- Set \uparrow upper limits \uparrow on pentaquark yields in both modes relative to the yield of the resonance $\Xi(1530)^0$.
- Simplify comparisons with other experiments.

Mode	@90% <i>C.L.</i>	@95% <i>C.L.</i>
Two Track Trigger Sample		
$\Xi^- \pi^+ / \Xi(1530)^0$	0.06	0.07
$\Xi^- \pi^- / \Xi(1530)^0$	0.03	0.04
combined statistics	0.07	0.08
Inclusive Jet 20 Sample		
$\Xi^- \pi^+ / \Xi(1530)^0$	0.06	0.08
$\Xi^- \pi^- / \Xi(1530)^0$	0.07	0.09
combined statistics	0.09	0.11

9 – Conclusions.

⇒ In a conclusion...

- CDF Collaboration conducted a search for a double strange $S = -2$ pentaquark states in $\Xi\pi$ decay modes.
- NO evidence of exotic baryon states has been found.
- CDF Collaboration is pursuing a vigorous program of a study on the possible pentaquark production at Tevatron.

THE END OF THE TALK.